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The use of virtual reality technology in teaching environmental engineering

Stephen Burnley

Abstract

The Open University (OU) provides a Diploma in Pollution Control as part of its undergraduate degree programme. The courses that make up the Diploma are presented in distance learning format using the OU's supported open learning system that has been developed over several decades. Teaching environmental engineering by distance learning presents several challenges in terms of ensuring that students gain an appreciation of the technology in action and receive the motivation and support more readily available to students taught in a campus setting. The OU has developed a multi-media resources DVD to help meet these challenges for students undertaking an environmental impact assessment project. The DVD contains virtual reality views of the proposed site, maps of the region, supporting technical data, interviews with experts and advice from a virtual tutor. A survey of students using the DVD found that the overwhelming majority found the DVD to be "very useful" or "useful". Understandably, the material that is essential for completing the project received the highest rating, but the background material was still considered to be useful by most students. Similar resources could benefit all students in many areas of engineering and technology.

Introduction

Virtual reality (VR) can be defined as a "computer-generated world" (Rheingold, 1991). At its most basic level, VR allows the user to explore a three-dimensional (3-D) environment such as a city centre using software that manipulates a series of photographs to present the view that would be seen through a camera located at a particular point or points in the environment. This virtual camera can be rotated through 360° by the user and a zoom control allows them to focus on a particular area in detail or to view a wide angle perspective.

In more sophisticated systems, the user can interact with the environment. For example, computer-linked gloves, tools or cockpit controls can be used to simulate complex manual operations such as surgery or flying an aircraft (Tuggy, 1998).

VR technology has obvious applications in education and training where potentially dangerous tasks such as flying or surgery are carried out. In other fields, VR allows students to pay a virtual visit to a location where a real life visit would be impractical. For example, students of geography can study remote landscapes or sensitive natural environments and engineering students can undertake virtual tours of industrial processes where real visits may be inconvenient or impossible on health and safety grounds.

Whilst VR provides opportunities to all students, it is particularly useful for those who are studying by distance learning rather than at a central campus. These, and other part-time students, are often excluded from site visits and field work due to their time commitments. This paper describes and discusses the use of VR as an aid to teaching environmental engineering to distance learning students at the Open University (OU) and presents the results of a survey of the first cohort of students to use the materials.

Literature review

Most of the literature on the use of VR in education and training relates to surgical applications (for example Park et al., 2007), but there are also reports of its use in engineering applications. Kuester and Hutchinson (2007) noted that the availability of laboratory infrastructure and resources limited student access to earthquake simulation equipment. This was overcome by the development of a VR shake table experiment. In the topic of bridge examination, similar problems were reported by Miyamoto, Konno and Rissanen (2007), who created a 3-D model of a concrete bridge

to be used by a specialist instructor to train civil engineers. This system was found to give better results than traditional teaching methods and had the added advantage that time-based deterioration could be simulated. In the case of manufacturing engineering Whitman et al. (2004) commented that project-based learning provided a valuable way of integrating knowledge gained from separate modules and of developing problem-solving skills. However, time and resources make it hard to find non-trivial projects in manufacturing engineering. A VR system of a manufacturing line in the aircraft industry was developed to address these areas.

In the environmental discipline, Ramasundaram et al. (2005) developed a virtual field trip to a specific site in Florida for undergraduate students. This was designed to help overcome the cost and time constraints restricting the use of real field visits. The system was developed over a one year period of intensive effort and testing, but the authors recognise that it can be reused and modified for other courses. It was also noted that it could have applications for distance learning students. Future work is planned to assess student use of the tool and to develop its use in distance learning.

Environmental Engineering at The Open University

The OU offers an undergraduate Diploma in Pollution Control comprising two 60 CATS points: Environmental Control and Public Health at level 2 and Environmental Monitoring, Modelling and Control at level 3. The Diploma can be used to contribute towards several OU bachelors degrees including the BSc (Technology), BEng and MEng. These two courses are also recognised by professional institutions. The Chartered Institution of Water and Environmental Management (CIWEM) classes them as preferred courses for students intending to use an OU degree to satisfy the academic requirements of CIWEM membership. The Chartered Institution of Wastes Management (CIWM) recognises the Diploma as satisfying the academic requirements of Licentiate Member grade and, in conjunction with other OU courses, the academic requirements for Corporate membership. The Diploma can also be used in an OU degree profile to obtain Chartered Engineer or Chartered Environmentalist status through a number of other professional bodies (Open University, 2007a).

In common with all other OU undergraduate modules, these courses are delivered using the OU's system of supported open learning. Under this system students study at home using specially prepared teaching texts, audio and video material and computer software. Each student is assigned to a personal tutor who supplies detailed feedback on their assignments, provides teaching support by telephone and e-mail and runs about 14 hours of face-to-face tutorials during the eight to nine months of the course.

The level 2 course

OU students are encouraged to obtain some experience of study at level 1 before embarking on a level 2 course. However, like all OU undergraduate courses, there are no prerequisites to Environmental Control and Public Health, so we have to assume that students are new to the discipline of environmental engineering and may have very little knowledge of science in general. The course begins with some basic material on chemistry, biology, mathematics and statistics followed by a brief review of the environment, environmental risk and public health. The bulk of the material is then taught through six topics:

- food processing and distribution;
- water pollution and control;
- wastes management;
- noise control;
- air quality management;
- environmental impact assessment.

Students are also required to undertake a number of environmental experiments using a kit provided by the University. Assessment is by means of six pieces of coursework and a three hour unseen examination.

The level 3 course

Environmental Monitoring, Modelling and Control builds on material introduced in the level 2 course and is taught through four main topic areas:

- potable water treatment;
- managing air quality;
- assessing noise in the environment;
- solid wastes management.

Students are assessed through a combination of continuous assessment and a unifying project report submitted at the end of the course. The continuous assessment comprises

four assignments, one for each of the subject areas outlined above, and the project consists of the environmental statement report as described below.

The course and assessment strategy are designed to ensure that students achieve the specified learning outcomes (Open University, 2007b). In summary, these outcomes cover a knowledge and understanding of the four subject areas, the development and use of computer models to predict and evaluate the effects of pollutants, financial assessments, critical analysis of technical and academic literature and communication skills. The project is designed to assess these cognitive and practical skills in a real world setting.

The forerunner of this course was first offered in 1989 under the title of 'Environmental Monitoring and Control'. Since then it has undergone major revisions in 1997 and 2004. Revision was partly necessary to maintain the relevance of the course in the light of the changing technology, legislation and policy on environmental pollution control. Revisions were also necessary to allow students to benefit from the rapid developments and availability of information and communications technologies (ICT). In 1989, home computing facilities were not widely available so computers and computer modelling were not used in the first version of the course. By 1997, it had become reasonable to assume that all students studying technology courses would have access to a personal computer and employers would expect environmental engineering graduates to have modelling skills. Consequently, computer modelling was introduced using "Mathcad"

software and electronic books written specifically for the course. Students were expected to have internet access and e-mail, but it was possible to complete the course without these facilities. By 2005, when the course was first presented in its current format, falling computing and Internet access prices allowed further developments and all students are now required to have access to a personal computer with internet access, a DVD drive, video software and either Microsoft "Word" and "Excel" or Sun Microsystems "StarOffice" (a package provided to OU students at no cost that includes word processor and spreadsheet applications that are compatible with "Word" and "Excel"). A summary of the developing ICT requirements of the students taking this course and provision of resources by the University is given in Table 1.

The environmental statement project

Under the requirements of the Town and Country Planning Regulations (Environmental Impact Assessment, England and Wales) (HMSO, 1999) and similar legislation covering Scotland and Northern Ireland, planning applications for a specified range of major infrastructural projects must be accompanied by an Environmental Statement – the product of an Environmental Impact Assessment (EIA). The types of project covered include airports, major roads, chemical process plants, power stations and the larger waste incineration processes. To undertake a comprehensive EIA requires a large team of experts (civil engineers, planners, lawyers, architects, ecologists and archaeologists as well as environmental engineering specialists)

Table 1. Information communications and computing requirements of different versions of Environmental Monitoring Modelling and Control

Year	Student requirements	Resources provided
1989	Audio cassette player Scientific calculator	Audio cassettes
1997	Audio cassette player Scientific calculator Personal computer with floppy disc drive. Microsoft "Windows 3.1"	Audio cassettes "Mathcad" software and electronic books
2005	PC with Pentium 2 GHz processor, 256 MB RAM, 6X DVD-ROM reader, video playing software, 56kbps (V90 or V92) or broadband modem internet access. "Microsoft Office" or "Sun Microsystems StarOffice"	Video DVD Resources DVD Sun Microsystems "StarOffice" On line conference access Course webpages Option of electronic submission of assignments

to investigate every potential impact of the proposal on people's health and wellbeing and on the natural and built environments. Such a project is well beyond the scope of a single undergraduate student, but a limited EIA still allows the students to demonstrate the key skills of environmental modelling, environmental impact assessment and pollution prevention/control technologies. The limited environmental statement produced by the students consists of the following sections:

- a non-technical summary;
- a description of the proposed site and justification of the process selected;
- an assessment of and recommended prevention/control measures for
 - water pollution
 - noise
 - air pollution
 - waste production and disposal;
- a more detailed investigation of one of these four areas (the area to be selected by the student);
- brief comments on the health effects on the general population and the workforce;
- references;
- appendices (to include supporting evidence of the student's modelling work).

This project, rather than an unseen examination, was selected as the end of course assessment for a number of reasons:

- it encourages the students to consider potential pollution sources and pollution prevention and control in an integrated manner (for example, removing the pollutants from a gas stream generates a solid or liquid waste which requires further treatment with its associated environmental impacts);
- the project requires a consistent effort throughout the course which is considered to be a better representation of a real working situation than a formal examination;
- the report is a definite output that students can show employers and potential employers;
- students have to develop good written communication skills and be able to present complex information to lay audiences.

One disadvantage of a project over an examination is that some part-time students find it easier to arrange their study time to allow for a concerted period of study and revision

over a shorter timescale than a constant effort over eight months. Another potential disadvantage is that some students may lose interest in the project over an extended period so the materials provided must be designed to maintain their enthusiasm throughout the course.

Each year the project is based on the same development, an integrated municipal waste management facility to be built on a brownfield site close to a town centre. The facility consists of a materials reclamation facility (MRF) to process materials collected for recycling, a waste composting operation, a municipal waste incinerator and administrative offices. Although the basic scenario remains the same, the specific areas that the students are required to address change from year to year. This allows the questions to take account of developments in environmental legislation and policy over the years and also reduces the risk of plagiarism from previous years. For example in one year students may be required to determine the likely impact that the sound emissions from the incinerator chimney have on neighbouring houses and design an acoustic chamber to reduce these sound levels. In the following year, the students may be required to discuss the measures to be taken to minimise the sound emissions from the compost shredding equipment.

The facility is based on a real proposal that was not developed, but various fictitious features were added to the neighbourhood to give greater flexibility in selecting the issues to be studied. These fictitious additions included a reservoir and water treatment plant, a hospital, an industrial estate, a site of special scientific interest (SSSI), a sewage treatment works and a commuter railway. In addition to these features, the large number of waste deliveries to such a site allows questions to be set regarding transport issues such as noise and air pollution.

The wide range of operations taking place on the site and the additional neighbouring features give ample opportunities for the students to investigate different aspects of the environmental impacts of the site each year. This is important, because the cost of producing the resources described below means that the basic situation and supporting resources will have to be used throughout the projected eight-year life of the course.

Resources provided

The previous version of this course presented all of the project material in a black and white booklet. The first part of the booklet described the proposed development, gave the required supporting data (for example noise levels from operating plant and pollutant emissions from process chimneys) and provided guidance on the content and structure of the report and on the writing style to be adopted. The second part of the booklet (which changed each year) gave the specific questions that the students had to address in their reports. Illustrations were limited to two outline maps of the area and schematic line drawings of some items of the process equipment. Student feedback indicated that many of them were not happy with the limited information given in the book and others became bored with the book (and sometimes with the project) as the course progressed.

When the course was re-written for presentation in 2005 the course team decided to produce a multimedia resource that would provide sufficient background information for the eight-year life of the course and maintain student enthusiasm for the project. This decision also had two secondary aims. Firstly, to give the students an excess of data and information to help develop their skills in selecting the resources that were necessary to answer the specific questions (an important skill for level 3 study). Secondly, the additional material was designed to give students the opportunity to

extend their interest and knowledge beyond the confines of the course learning outcomes.

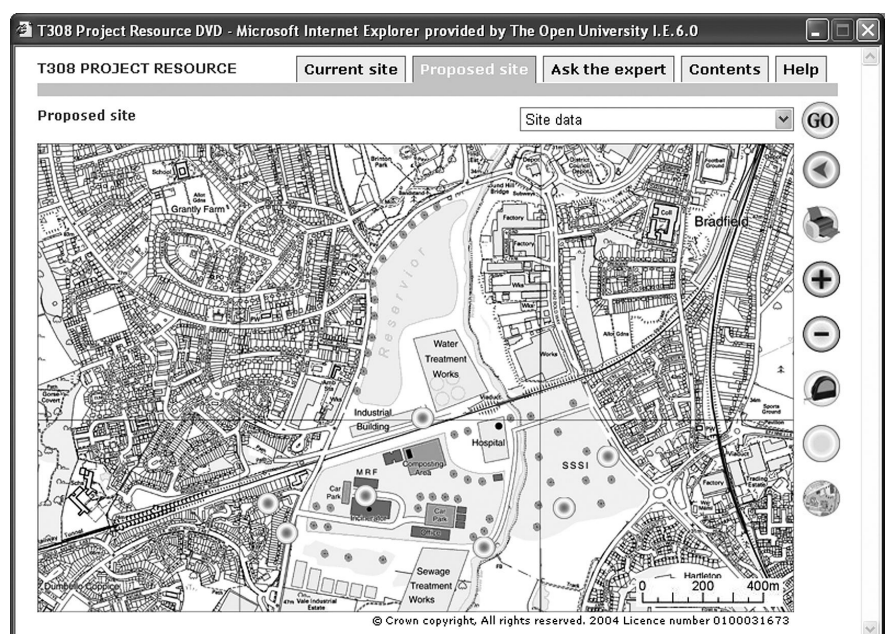
The resources described below are all contained on one DVD which also includes the software necessary to operate the VR and other material. When the DVD is run, the opening screen gives students a menu where they select the project resources, the project advice (the virtual tutor described below), the course computer models or a help facility. On selecting the project resources a set of tabs and drop down menus guides the students to the maps, virtual reality and other resources discussed below.

Maps and virtual reality

On opening the project resources, the student is presented with a selection of maps of the area (Figure 1). The maps are available at three scales; approximately 1:32,000, 1:13,000 and 1:6,000 and show the area before and after the proposed development has been built. The two larger scale maps have the option of showing the VR centres and clicking on any centre takes the user to the VR views. All the maps have a measuring facility that allows the user to determine the distance between any two points on the map. This is an important feature when modelling the dispersion of noise and air pollutants. For example a question may require students to determine the exposure to noise of people living adjacent to the site or to model the potential impacts of nitrogen oxides deposition on the SSSI.

Figure 1.

1:13,000 map of site after development showing VR hotspots



The maps lead the student into the VR views which simulate the effect of standing at the centre of the site or at one of six points surrounding the site (Figure 1). The user can use the controls to look anywhere around the site and to zoom in or out when they wish to see more detail or a broader picture (Figure 2). To provide links to the other resources the VR views contain hotspots where clicking takes the user to the centre of other VR views, the text, video and other resources described below. While using the VR, the screen also displays a small sketch map showing their current location, the direction they are looking in and any neighbouring VR centres (Figure 2).

VR has the advantage that scenes can be created by merging photographs from many different locations. In this case the basic site photographs (taken in the West Midlands) were supplemented by photographs from Milton Keynes, East Anglia and Hertfordshire. The addition of photographs from several waste management sites in Southern England allowed the production of VR views of an architect's impression of the completed development.

Textual information

In previous versions of the course, the only source of information given to students was

in the form of the project booklet described above. A printed project guide is still used because it has the advantage of being relatively cheap to produce and can be updated each year with the relevant specific questions that must be addressed in the project and references to information relating to these questions in the course materials. It is also considered that the printed guide is the best place to present advice on the writing style and instructions about submitting the project. Given that some printed information is required, the opportunity was taken to include the background material to the proposed development and key data items.

Whilst the printed information is useful for students who prefer to work in this way, much of the data is also presented in text form alongside the visual information on the DVD (Figure 3). For example, if a student wishes to determine the microbial emissions from the composting site, they can access this through a drop-down menu on the DVD or they can click on the composting equipment on the VR image. This information is also presented in the printed guide, but the electronic access gives more immediacy to the data and it has the added advantage that it can be copied and pasted directly into the student's report.

Figure 2.

VR view of developed site showing site sketch map

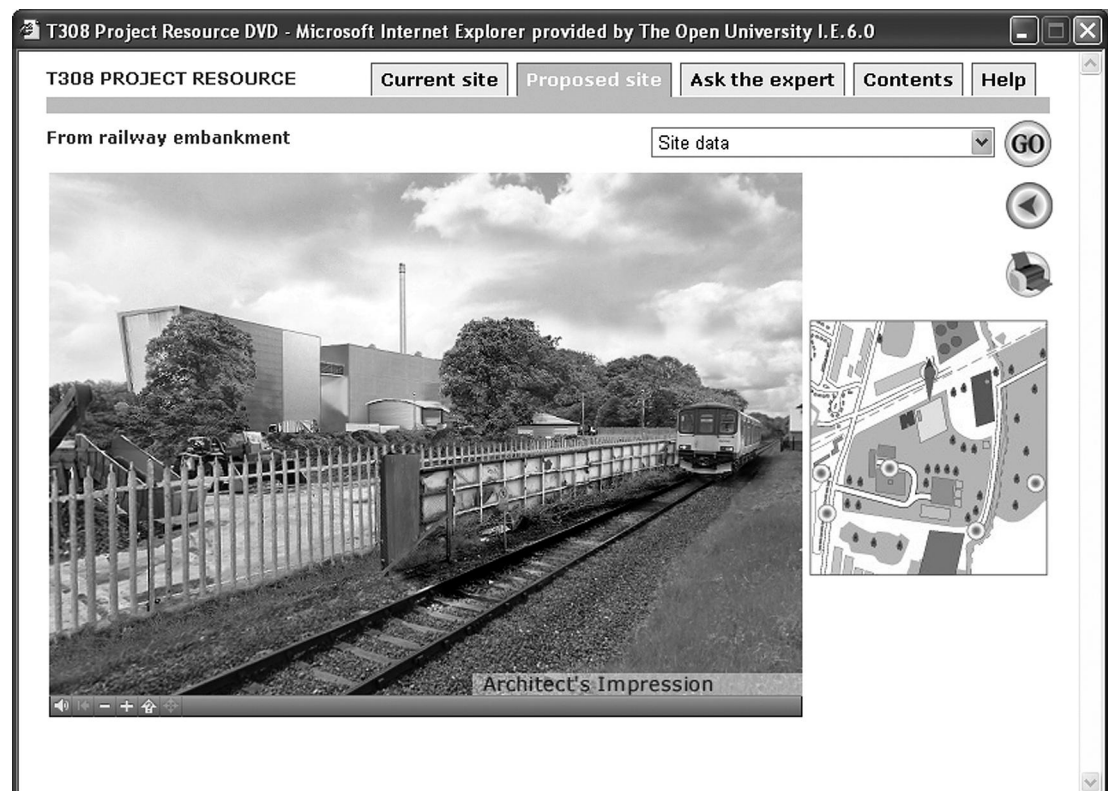


Figure 3.
Sample of text
information

Bioaerosol emissions - Microsoft Internet Explorer provided by The Open Univer...

Bioaerosol emissions

Emissions table (using an Andersen Sampler for viable micro-organisms).

Weather conditions.

Date	Weather/rain	Cloud Cover	T (°C)	RH (%)	Windspeed (mps)
Summer	Dry and warm	(0/8—7/8) 4/8	(16—26) 23	(42—57) 50	0.28 average, gusts to 0.7
Autumn	Damp, rain in the days before	(4/8—7/8) 5/8	(9—14) 11	(81.7—90.1) 88.2	0.3 average, gusts to 0.6
Winter	Dry and sunny, breezy	(3/8—6/8) 4/8	(8—10) 9	(92.9—90.1) 85	0.65 average, gusts to 1.1

Bacteria exposure time 2 minutes.

Details of siting	summer cfu/m ³	autumn cfu/m ³	winter cfu/m ³
Mid-site	428850	104950	10212
Upwind	6890	203	274
40/50 m downwind	3949	428600	8375
100 m downwind	6511	6519	1193
150 m downwind	2102	353	2155
180—200 m downwind	309	133	4602
230—250 m downwind	822	159	1493

Figure 4.
Advice from
the Virtual Tutor

Getting started - Microsoft Internet Explorer provided by The Open University I.E.6.0

Getting started

- [Getting started](#)
- [How you do it](#)
- [Tools to help you](#)
- [What you need to do](#)
- [Be thorough](#)
- [Putting the project together](#)



00:03 03:12

Video clips

A major problem faced by part-time and distance learning students is that it is difficult, if not impossible, to arrange visits for them to see the technologies discussed in the course and used in the proposed project development. This was partially overcome in this course by providing all students with the DVD-video supplied to the level 2 course students that shows a number of waste and water treatment processes.

In addition, a set of five to ten-minute video clips were compiled which would be of direct relevance to the project. These clips covered:

- the operation of composting, recycling and incineration processes;
- the operation of schemes to collect recyclable materials from individual households;
- the treatment of water for drinking water supply;
- sewage treatment;
- the operation of a landfill for incineration residues.

Like the other resources, these can be accessed from either the VR hotspots or from drop-down menus on the map pages.

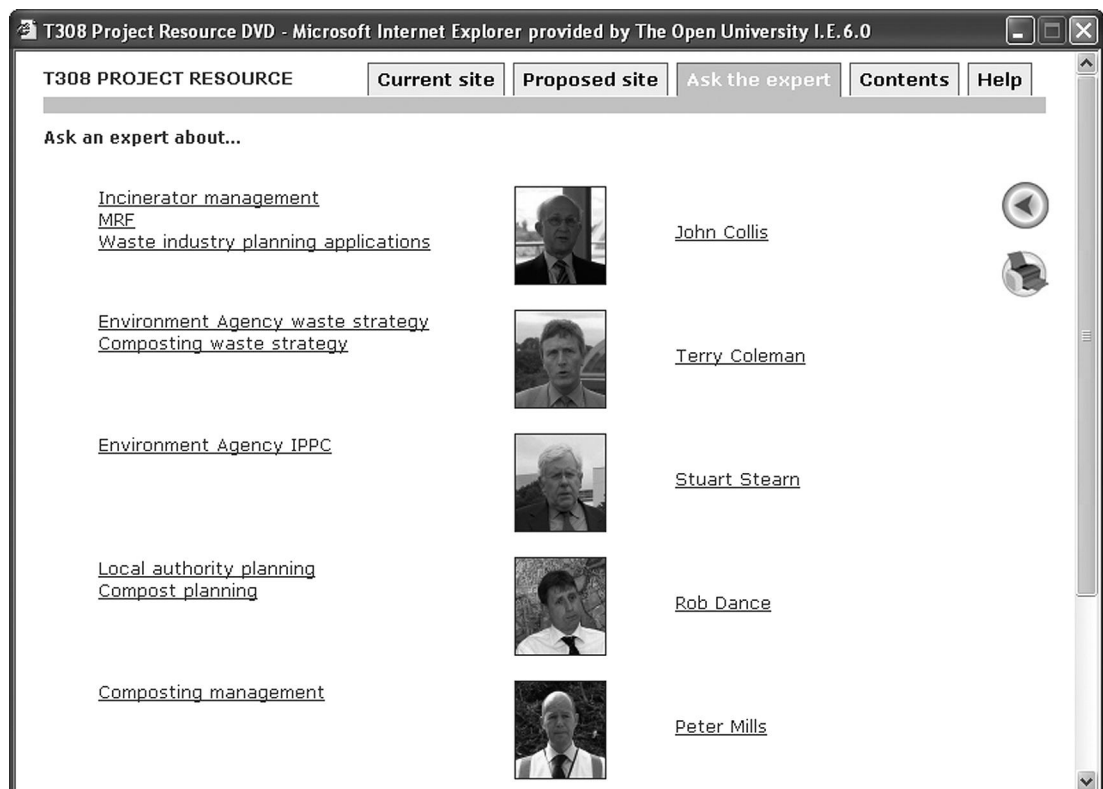
Virtual tutor

Each time the students run the resources DVD they are given an option of accessing a project advice screen. This consists of a series of video presentations given by an actor taking the role of a course tutor or member of the course team. In the video presentations, the tutor discusses the process of undertaking the project (Figure 4). The initial clip consists of a three-minute introduction to the project that sets out the student's role (that of an environmental consultant) and introduces the proposed plant and the nature of the required environmental statement. Further practical advice is given about the timing of the project and the need to work on the statement throughout the course. The other video clips give more specific advice on doing the project, the resources and tools provided and assembling and submitting the final document.

Expert interviews

A series of interviews were held with outside experts for the students to view. These took the form of a set of questions that the course team predicted that the students would like to ask the experts. The questions tended to focus on the development and use of the EIA which helped to set the project in context. The experts' responses were then filmed and added

Figure 5.
Ask an expert
opening page



to the DVD with a brief biography of the expert. The experts used (Figure 5) were:

- operators of recycling, composting and incineration plants;
- a waste management company employee who led an application for planning permission and an Integrated Pollution Prevention and Control (IPPC) permit from the Environment Agency;
- an Environment Agency officer responsible for assessing IPPC applications;
- a local authority waste planner;
- the Environment Agency's national waste strategy manager;
- an ecologist.

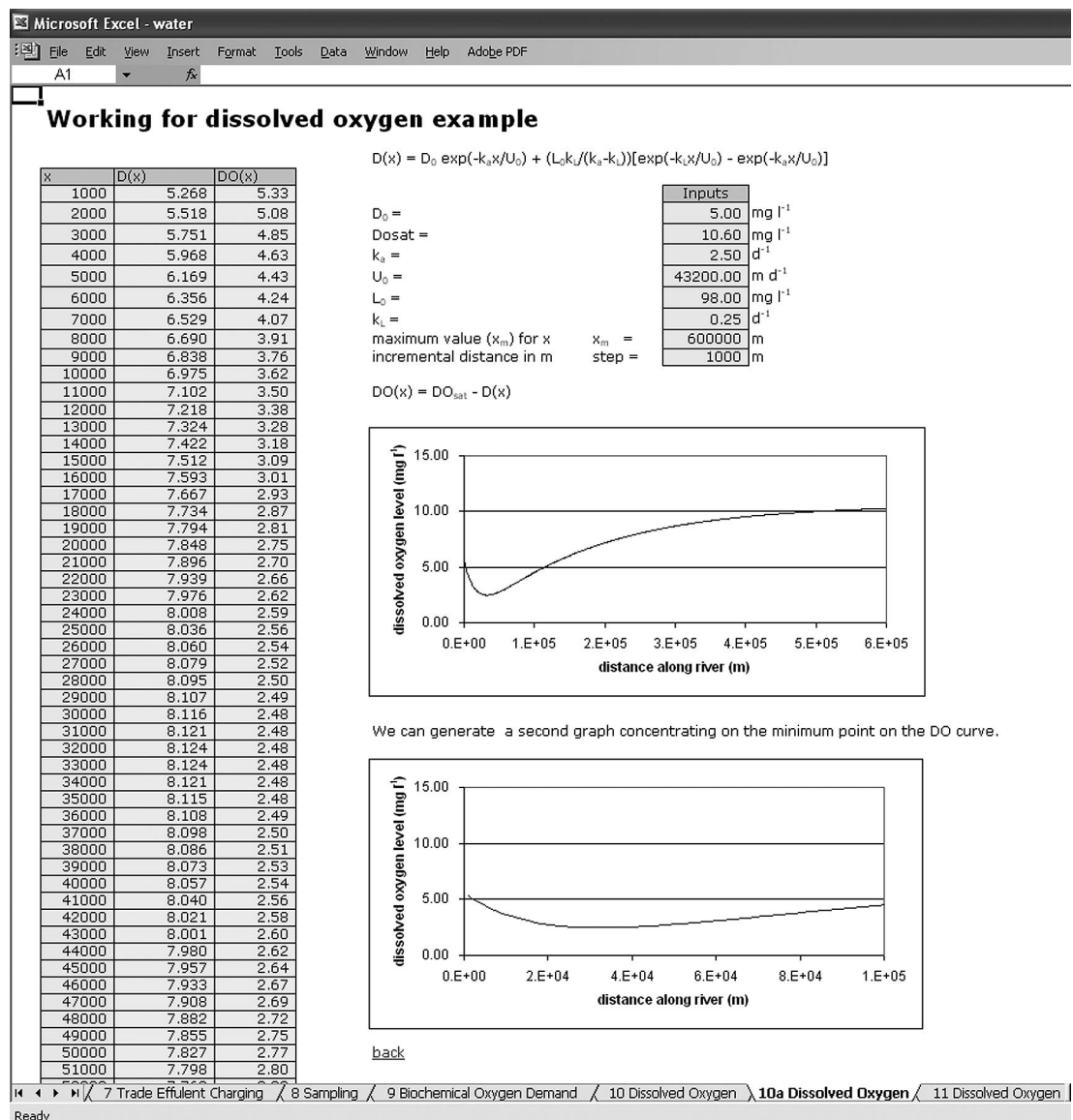
This enables the students to hear the sometimes conflicting views of the experts about the same question (for example the

different concerns of the local planning officer and the Environment Agency strategy manager) and to hear about some of the day-to-day issues that arise during construction and operation of the processes.

Computer models

Using computer models and interpreting the output from models forms a key element of the course as a whole and of the project. A set of models is provided on the resources DVD. Most of these are in the form of spreadsheets ranging from a simple tool to convert pollution concentrations from volume to mass units, through air pollution dispersion models to a complex model using several spreadsheet worksheets to model the implementation of a county-wide waste management strategy. In addition, a demonstration version of a commercial life-cycle assessment model is

Figure 6.
Sample
spreadsheet model



provided. An example of a model that predicts the dissolved oxygen level downstream of a pollutant discharge is shown in Figure 6.

Survey of student use of the VR and related resources

At the end of the first presentation of all OU courses an anonymous postal questionnaire survey is carried out of all the students who completed the course (in this case by submitting the project). This questionnaire covers a set of general questions common to all courses and a set of questions specific to the course. In this case, the course-related questions focused on the project and DVD material. 172 questionnaires were posted to the students and 91 were returned; a response rate of 53%.

Reasons for studying

The results of the questionnaire showed that most of the students were taking this course for specific reasons. 37% of respondents stated "career progression" as their main reason for taking the course and 40% said their aim was to enable a career change (it should be noted that these answers were not exclusive so some students may have cited both reasons). 36% of students had received financial support from their employer and over 99% were taking the course as part of a programme leading to an OU award (degree or diploma). These results are typical of courses offered in the science and technology areas at level 3 where relatively few students study purely for general interest or personal development.

Use of the DVD resources

In the questions relating to the DVD the students were asked to rate the usefulness of each of the five features of the DVD discussed above using the following four point scale:

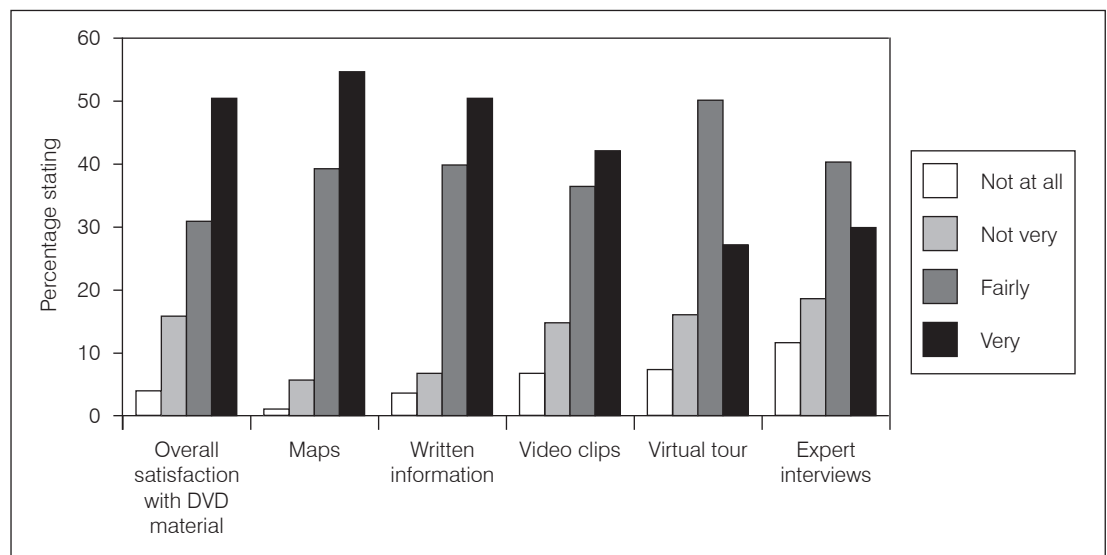
- 1 Not at all
- 2 Not very
- 3 Fairly
- 4 Very

The responses are summarised in Figure 7. Overall satisfaction with the DVD was high with 81% of those who used the DVD rating it as being "fairly useful" or "very useful". It is interesting to see that, in spite of the need to use the DVD to complete the project, 3.3% of respondents (i.e. three students) said that they did not use this resource at all.

Regarding the specific features, the interactive maps and VR proved to be the most useful (93% of respondents giving a score of 3 or 4). This may reflect the fact that the maps are equipped with a measuring device and students are required to measure distances in both the air and noise questions of the project. It is possible to obtain these measurements from the scale maps supplied in the printed project guide, but this is far more difficult.

The written information on the DVD was judged to be almost as useful as the maps. This is also not surprising, because it is not possible to complete the project without using some of this information. Inspection of the final projects

Figure 7.
Student satisfaction
with the
Resources DVD



Note: the first column neglects 3.3% of respondents who said that they did not use the DVD

showed that many students made use of the facility to paste data tables directly into their reports.

The video clips were regarded as less useful than the maps and information. These clips are designed to provide background information, but their use is not an essential part of the project. Furthermore, some of the clips are of the types of facility that have been presented on video in the level 2 course so will not be new to many students.

The inclusion of the virtual tutor is a technique that had not been used before by the OU so, as well as giving a simple rating, students were asked to write down their views on the use of this technique. Of the students who answered this question 56% were supportive of the idea, 11% expressed a neutral opinion, 17% actively disliked the idea and 17% did not use it (Table 2). Most of the students in the latter group also had problems with running the video material from the DVD so they may have used this feature had they been able to do so. The main comment from students who supported the technique suggested that it personalised the material and others noted that it was "better than text", that it "highlighted the main points" and "kept me on track". The neutral comments generally suggested that the tutor's advice was too simple for a level 3 course or not really necessary. The students who disliked the technique expressed the views of the neutral students, but much more forcefully suggesting that it was "unnecessary", "long-winded" and "boring". Others disliked the presentational style.

The expert interviews were regarded as the least useful of the features with 40% rating them as fairly useful and 30% very useful. Like the video clips, they were intended to provide background information. For example, the

experience of compost plant operators and the procedure for obtaining a permit to operate under the Integrated Pollution Prevention and Control (IPPC) system would help the more-able students produce a better project report, but are not essential aspects of the project. Many students are limited in the amount of time they can devote to studying so it not surprising that this non-essential feature was ranked lower in terms of usefulness.

Discussion

All distance learning students, and particularly those engaged in engineering courses, face several problems in comparison with their peers. Physical isolation from their tutor and fellow students is perhaps the most obvious. Also, distance learning engineering students are usually unable to take part in site visits to experience the technology in action. Those undertaking project-based courses, which teach vital transferable skills, need to be given the resources normally available to other students in academic libraries and also need the support and stimulation necessary to work consistently for an extended period while there are many other demands on their time.

The OU has worked to overcome these problems for over three decades and has always exploited ICT to the full. The level 3 course Environmental Monitoring, Modelling and Control makes use of a novel VR system supported by maps, video material, text, expert interviews and a virtual tutor. Student feedback gave this resources DVD a high overall satisfaction rating. Student views of the usefulness of the individual components of the DVD reflect the importance of each component in completing the project. Essential features such as the maps and written information rated at over 90% whilst the expert interviews (which provided background information and insights) rated a lower, but still good score of 70%.

Table 2. Summary of responses to students' opinions of the virtual tutor

	Number of respondents	Percentage
Supportive	47	56%
Neutral	9	11%
Disliked	14	17%
Didn't use	14	17%

Note: excludes the 11 respondents who did not answer this question.

Neutral or negative comments about the virtual tutor tend to suggest that a significant minority of the students found it unnecessary or too simple for their level of study. However, the 77% of students who approved of the feature said that they found it supportive and useful. It may be that a virtual tutor would be even more valuable to students at an earlier stage in their university courses.

Several students reported problems in running some or all of the DVD resources. Before enrolling on the course, students are given details of the minimum computer specification necessary to run the software. However, anecdotal evidence from the students' on-line forum suggests that some students had equipment that did not meet this specification. Other students had added hardware (such as external DVD drives) that had not been correctly configured. Whilst such students could be blamed for their problems, they are still missing part of the learning experience and will require additional support in order to complete the course. Institutions using such technologies need to be extremely clear to potential students about computer specifications and offer telephone or online helpdesks to deal with problems (as indeed the OU does). Furthermore, during development these resources need to be tested using the minimum specification computers to assess access times and the likelihood of system failures while using the software at the same time as other programs such as word processors. Consideration should also be given to producing cut down text-only versions of the software to allow students using lower specification computers to access at least some of the resources.

Understandably, "passing the course" is a key aim of many, if not most, students. Family, work and other commitments mean that part-time and distance learning students are often time-poor. Therefore it is not surprising that, during their studies, they concentrate on the resources that are essential to achieve the aim of passing the course: in this case, the maps, texts and directly-relevant material on the conferences. Whilst enrichment material should not be excluded from computer and internet resources, it should be noted that the use of these facilities may not be as great as was hoped.

The student survey was a standard questionnaire used by the OU to evaluate all its courses so it did suffer from some deficiencies. For example, it did not collect any data on respondents' age or gender, but there may be significant age or gender differences in the value of different aspects of the resources to the students. In addition, with the exception of one free-form paragraph, students were restricted to providing answers to a set of specific questions, so areas of importance may have been neglected. Further research on the use of this DVD is currently taking place in one of the OU's Centres for Excellence in Teaching and Learning (CETLs) under funding from the Higher Education Funding Council for England (HEFCE). In particular, the DVD has been discussed with student focus groups at various stages of their studies and the results from this will be published in due course.

The material contained on the resources DVD was time-consuming to produce. Like Ramasundaram et al's (2005) VR field trip, the DVD took about one year to produce. In common with Ramasundaram's system, the costs of producing the material can be justified due to its flexibility and potential for reuse. Furthermore, because it is delivered by distance learning, there are no staff costs associated with using the resources. The on-going research described above is therefore essential in determining how future DVDs can be developed to give the maximum possible benefit to the students in terms of achieving the course learning outcomes and at the lowest cost consistent with high production standards.

The resources described above are also being used in several other OU courses in both the humanities and scientific courses. For example, the cross-faculty level 1 course in environmental studies (to be presented from 2009) includes expert interviews with researchers, video materials of environmental research in practice and a virtual exhibition of life, science and art in the Arctic. The level 1 course, *Discovering Science*, uses DVD technology to present a virtual field trip to the Galapagos Islands, to investigate the three-dimensional structure of molecules and explore climate models. A proposed Masters-level module in waste management will also use VR material in the operation of waste management installations.

Conclusions

VR technology is used in several applications to take people to remote or dangerous environments where visits are not practicable. In this application, VR was combined with other teaching materials to produce a resource for students studying environmental engineering by distance learning.

VR has been widely used in teaching surgical techniques and, to a lesser extent, engineering. There is less published information on its use in environmental education or for distance learning purposes. This study demonstrates one way in which VR technology can be applied to environmental engineering students in distance learning applications, although there is no reason why it would not also provide a valuable resource to campus-based students.

A survey of student use of these VR resources gave very positive results. The overwhelming majority of students found the materials to be "very useful" or "useful". The most valuable resources were those that formed an essential part of the course, while the background

material received a lower rating. This is not surprising, given the constraints on part-time students' time.

Some students experienced problems running the resources and this appears to be mainly due to student computers not meeting the recommended specification or having incorrectly configured hardware. This needs to be considered when producing such resources.

VR technology has many potential applications in education for both campus-based and distance learning students and the OU is making use of VR in a range of disciplines including the humanities, sciences and technology. Other potential engineering applications of VR in teaching include construction, manufacturing, chemical processing, off-shore, deep sea, space and military engineering.

Further research is continuing to gain a deeper understanding of student use of the different aspects of this VR resource. ■

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